APPENDIX A
HISTORICAL HAZARDS

This appendix discusses the principal radiological, chemical, and physical hazards present at ORGDP, and the potential effects from worker exposures to these hazards.

Radiological Hazards

The radioactive hazards associated with ORGDP operations and supporting activities included uranium and its daughter products, transuranics, and fission products. From 1949 into the mid-1960s, the AEC sponsored numerous studies of the radiological effects of neptunium, plutonium, technetium, and other fission products and transuranic elements that were found in low concentrations in incoming reactor tails. Plant-wide studies determined that the impurities tended to concentrate in certain areas of the feed manufacturing plant, oxide conversion plant, cascade, equipment, and process piping.

A number of consensus standards were established to provide guidance for the protection of personnel from the inherent hazards associated with the handling of radioactive materials. These standards included the Radiation Protection Guides (RPGs) established by the Federal Radiation Council, the requirements of AEC manual chapters (subsequently ERDA and DOE orders), and those established by the NCRP and the National Bureau of Standards Handbook 69. AEC policies also encouraged the maintenance of personnel radiation doses as far below applicable standards as was practical. These policies and standards were essential factors in hazard identification and control throughout the AEC complex of the period. While management policies at ORGDP embraced the intent of the consensus standards in protecting personnel from radiological hazards and exposures, evidence clearly indicates that they were not rigorously implemented and enforced by ORGDP line managers.

Uranium is a naturally occurring element in the earth and is mined for commercial purposes. Natural uranium is 99.3 percent uranium-238 and 0.7 percent uranium-235. Uranium-235 is used as nuclear reactor fuel and in some nuclear weapons. Enriched uranium contains more uranium-235, and depleted uranium contains less uranium-235, than natural uranium. Uranium-238 has a radioactive half-life (the period for material to decay to half of its initial radioactivity) of 4.47 billion years. Once in the body, uranium may concentrate in the kidneys, bones, or lungs, depending on its solubility. For insoluble forms, radiation dose to the lung is a predominant concern. The principal sources of internal uranium exposures at ORGDP relate to the inhalation or ingestion of primarily soluble forms but include insoluble compounds in some areas, such as the oxide conversion (K-1410 and K-1420) and feed production (K-1131) facilities. Uranium hexafluoride (UF_6) existed at K-25 as a gas, liquid, and solid. Other compounds of uranium, such as uranium tetrafluoride (UF_4), uranium trioxide (UO_3), and triuranium octoxide (U_3O_8), have been present in significant quantities in the feed manufacturing plant, decontamination, recovery, and oxide conversion. There is evidence that workers were exposed to uranium in forms that could cause adverse health effects.

Uranium daughter products are produced when uranium decays by the emission of alpha radiation to produce other radioactive isotopes in the decay chain (called daughters). When uranium is melted or separated by chemical or physical means, less-dense daughter products, such as thorium-234 and protactinium-234m, can be concentrated. Protactinium-234m has a 26-day half life and is the major contributor to radiation exposures incurred during ash handling operations. Further processing can leave significant quantities of these daughter products in oxides or ash, or on the surface of process vessels. Daughter products were present in varying amounts at the feed manufacturing plant fluorination towers, primarily from ash receivers and the sintered metal (barrier) filters; in K-1131, K-1401, K-1410, and K-1420 from converter and compressor disassembly and maintenance work; in product feed/withdrawal stations; in cylinder cleaning stations; in raffinate from uranium recovery; in cylinder heels; and in other areas of the cascade. The beta radiation dose rate from concentrated residual daughter products is much higher than from the original uranium. In addition, daughter products in the form of fine particulates (like dust) are easily transferred by contact. Exposure to daughter products from transfer to clothing, tools, or other items is likely to result in unanticipated beta radiation doses to and potential ingestion by workers. Protactinium-

234m emits a high-energy beta particle, which contributes most of the beta dose from the uranium-238 daughter products.

Transuranic elements have atomic numbers greater than 92 (i.e., greater than uranium) and can be produced when uranium absorbs neutrons as part of a nuclear reaction. The principal transuranic elements of concern are neptunium and plutonium. Both are alpha emitters that have very long clearance times in the body. Transuranic elements were introduced to ORGDP from early experiments with Hanford Site waste and supernate, in materials received from other AEC sites, from uranium feed from processed spent reactor fuel, and from reuse of cylinders containing transuranic contamination.

- **Neptunium-237** has a radioactive half-life of 2.14 million years and is far more hazardous than natural uranium. The specific radioactivity of neptunium-237 is 2,000 times higher than the radioactivity of depleted uranium. The low concentration of neptunium found in reactor tails feed material was not a significant radiological hazard, and at such levels the controls for uranium would protect personnel from exposure to neptunium. However, neptunium did concentrate at certain points in the uranium conversion, enrichment, and recovery processes. The highest concentrations were likely associated with fluorination tower ash, research and development, decontamination, recovery, oxide conversion, and the waste streams associated with that process (i.e., K-1004 series laboratories, K-1401, K-1410, and K-1420). There were also milligram quantities of neptunium in the cascade feed areas, which could have presented the potential for exposures during CIP/CUP activities.

- **Plutonium-239**, as early as 1949, was thought to present a potential hazard to workers as a result of processing recycled materials from the Hanford Site and Savannah River Site. Plutonium is significantly more radioactive than neptunium, but was less of a hazard at ORGDP because it was present in much lower concentrations. It has a radioactive half-life of 24,065 years. Once plutonium reaches the bloodstream, it accumulates primarily in the liver and skeleton. Plutonium exposure may produce acute health effects (e.g., ingestion may lead to damage to the walls of the gastrointestinal tract) or long-term effects, such as increased risk of cancer. When plutonium is inhaled, the lungs are exposed to alpha-particle radiation, which increases the risk of lung cancer, and the plutonium is eventually carried to other organs where the radiation can cause cell damage and increase the likelihood of biological effects. Recent estimates indicate that while only a small amount of plutonium was present in the uranium fed into the ORGDP cascade, plutonium was likely present in research and development areas at the site and was concentrated in the uranium conversion, enrichment, and recovery processes. In addition, the relatively low levels of plutonium in the bulk recycled reactor uranium were concentrated to appreciable levels in the feed manufacturing plant. The highest concentrations were associated with the fluorination tower ash in the feed plant, decontamination, recovery, oxide conversion, and the waste streams associated with those processes (i.e., K-1004 series laboratories, K-1401, K-1410, and K-1420). There were also small quantities of plutonium in the cascade feed areas, which could have presented the potential for exposures during CIP/CUP activities.

Fission products are formed when neutrons split uranium-235 atoms during a nuclear reaction, and typically have atomic numbers in the range of 80 to 108 and 125 to 153. By far, the predominant fission product of concern in the ORGDP cascade was technetium. However, a number of other fission products (e.g., strontium-90, iodine-131) were introduced to the site through work for other AEC sites. Technetium-99 is a weak beta emitter with a radioactive half-life of 213,000 years and was introduced at ORGDP primarily from Paducah product. In addition, a small amount of technicium-99 was introduced from recycled reactor feed generated at the Plant. The primary exposure pathways are ingestion or inhalation. Protective clothing would adequately shield the low-energy beta particles emitted by technetium. Technetium passed through the cascade as a volatile compound of fluorine, depositing on internal surfaces of the cascade and contaminating the uranium product. The AEC did not specify a limit for technetium in UF_6 feed but controlled the concentration of technetium indirectly to about 10 parts per million (ppm) by limiting gross beta due to fission products. In addition, some uranium enrichment customers established a 10 parts per billion (ppb) limit on technetium in product cylinders. There was evidence that workers had some exposure to technetium.

Chemical and Toxic Metal Hazards

The uranium enrichment operations at ORGDP exposed workers to a wide variety of chemical and toxic metal hazards. Some of these hazards and their health effects were known from the early years of the Plant's history, such as mercury, fluorides, carbon tetrachloride, and TCE. Other hazards, such as epoxy resins, were recognized at the start of the centrifuge project. However, the hazards of some substances, such as PCBs and asbestos, were not recognized until the 1970s. As knowledge of the health effects of hazardous chemicals increased, permissible exposure levels have generally decreased. Accordingly, many of the limits established in the 1950s would not be acceptable today. The issuance of the OSHA hazard communication standard in 1983 drove improvements in chemical hazard identification at ORGDP. The hazard communication standard required the identification of chemical hazards, chemical labeling, development of chemical hazard program documentation, worker training, and most importantly, manufacturer development and dissemination of material safety data sheets (MSDSs) to chemical purchasers.

A number of health studies on the effects of these chemicals on ORGDP workers performed since 1960 reflect a divergence of opinion. A 1966 Union Carbide Corporation study concluded that the total number of deaths of Union Carbide employees during the period 1950 though 1965 was significantly lower than the average death rate in the United States during this period. However, a 1994 mortality study among workers between 1945 and 1984 conducted by ORISE concluded that there were statistically significant excesses of deaths due to cancers of the respiratory system, including lung cancer in the 1970s and 1980s, and due to chronic kidney disease in the 1980s. Statistically significant increases in deaths from all respiratory diseases were noted in the 1960s and continued through the 1980s. Mortality studies on ORGDP nickel workers conducted by the Oak Ridge Associated Universities (ORAU) and the National Institute of Occupational Safety and Health (NIOSH) in 1978 and 1998, respectively, showed no increased risk of mortality due to respiratory cancer among exposed workers. In 1989 and 1994, ORISE conducted studies on ORGDP centrifuge workers exposed to epoxy resins. Results from the Phase I study concluded that ORGDP centrifuge workers had greater than a seven-fold increase in risk for developing bladder cancer compared to the general population. The Phase II study did not confirm the increase in bladder cancer found in Phase I but identified an excess of temporary symptoms associated with solvents and resins. Since 1995, several studies have been performed on ORGDP workers concerning occupational exposure to cyanides. Studies performed by the University of Alabama, NIOSH, the State of Tennessee, and most recently a group of independent physicians indicate that although a group of former ORGDP workers have health issues, there is no clear link to cyanide emissions from or cyanide contamination at ORGDP.

The following paragraphs summarize alphabetically the principal worker hazards and the uses of, and exposures to, toxic metals, irritant gases, and solvents at ORGDP during the period 1945 until 1997.

Acids and alkalies are strong lung irritants and cause respiratory distress, burns to the skin and damage to the eyes. Reactions of acids and alkalies with other materials often produce violent reactions or explosions and can result in the evolution of toxic gases. Hydrogen chloride, for example, is a strong acid when dissolved in water and is a severe irritant to the eyes and respiratory tract. According to former workers, a wide variety of acids (hydrochloric acid, sulfuric acid, and nitric acid) and alkalies (ammonia, sodium hydroxide) were used in many ORGDP buildings throughout the decades. Acids were used for decontamination operations in K-1401, K-1420, and K-1131; as part of uranium recovery in K-1303; and in process development in the laboratories. A 1946 airborne chemical contaminant study, performed by the Carbide Corporation, noted that over half of the air samples in the acid bath area in K-1401 were over the Plant's MAC limit of 10 ppm for hydrochloric acid (HCl), with one analysis showing 110 ppm of HCl. In 1948, airborne acid concentrations in K-1004A were also reported as exceeding the Plant's MAC of 10 ppm. In the 1980s, one former worker recalls that during sample preparation in the K-1420 laboratory, the addition of HCl to an organic degreaser solution from K-1401 caused a violent reaction that resulted in acid burns to the face and neck. The worker's safety glasses precluded any eye injuries. Ammonia was used in K-1303 for uranium recovery and development, and in 1946 air surveys found that nearly half of the air samples had ammonia concentrations in excess of the 100 ppm MAC, with one analysis showing 350 ppm.

Perfluorobutyric acid was used in site operations and is a colorless liquid with a sharp odor similar to butyric acid. The vapors are extremely irritating to the skin and may cause severe chemical burns to the skin, eyes, and respiratory tract. The material is incompatible with water, reacting with water to produce corrosive fumes. It is not a carcinogen, and a TLV has not been established for this chemical.

Aromatic hydrocarbons and other solvents were in frequent use at ORGDP, although generally in lesser quantities than the chlorinated hydrocarbons (see "Carbon tetrachloride," below). **Benzene** was a common aromatic hydrocarbon solvent used in the K-1401 and K-1420 electrical and instrument maintenance shops until the mid-1950s. Benzene is volatile, and extended exposure to the vapors causes damage to the central nervous system, the gastrointestinal tract, and bone marrow. Prolonged exposure has been linked to an increased risk of cancer, particularly leukemia. In the 1950s, benzene was also a common component of paints, and painters in the painting shops were cautioned on its use. It was evident that ORGDP workers, like other workers throughout industry, were exposed to these solvents, and some had limited knowledge of or regard for the short-term or long-term health effects. By 1977, benzene use had been reduced at ORGDP, and was limited mainly to analytical laboratory extraction procedures. Other aromatic hydrocarbons to which ORGDP workers were exposed included toluene, xylene, and ethyl benzene.

Acetone was used at ORGDP as a solvent component for paints, lacquers, varnishes and plastics. In high vapor concentrations it irritates the eyes, nose, and throat. It also produces narcosis in high concentrations, with symptoms of headache, nausea, dizziness, loss of coordination, and unconsciousness. It may produce a dry, scaly dermatitis after repeated skin exposures. The TLV for acetone vapor is 500 ppm as a time-weighted average. Acetone should also be considered a potential fire hazard, with a low flash point of 0 degrees F.

Arsenic exists in organic or inorganic forms, and all are toxic. Non-occupational exposure to arsenic can come from drinking water, food, polluted air, and cigarettes. Symptoms of chronic arsenic poisoning include illness and fatigue, with stomach and intestinal distress. Arsenic is a carcinogen, causing increased risk of skin, liver, and lung cancer. Arsenic has been identified in several areas of the Plant, including the fluorine generators, process gas and converter maintenance, wood preservatives in the cooling towers, and coal and coal byproducts in the steam plant. Arsenic also naturally occurs in coal and has accumulated in slag and ash deposits inside the fireboxes and on the boiler tubes of the ORGDP electric power plant and the K-1501 steam plant during the periods that these plants were fueled with coal. Both plants were fueled with coal from about 1944 to1950, and the steam plant was again fueled with coal from the mid-1960s to 1990. Arsenic was discovered in firebox slag when slag from the steam plant was analyzed in 1989. Since this discovery, respirators have been required for firebox descaling, but before that time, workers inside fireboxes wore only paper dust masks for respiratory protection during descaling. The health effects for workers exposed to arsenic, especially in the process system, are indeterminate.

Asbestos, as airborne fibers, can be inhaled or swallowed, and these fibers can become embedded in the tissues of the lung and digestive system. Normally, there is a latency period of 15 to 40 years before the effects of asbestos exposure manifest themselves. Asbestos-related diseases include asbestosis (scarring of the lung tissue), lung cancer, and mesothelioma (cancer of the lining of the chest or abdomen). The most common asbestos-related disease, asbestosis, involves a progressive reduction in respiratory capacity and insufficient cardiopulmonary output which can result in death. Asbestos was not evaluated as a significant exposure risk at ORGDP until the late 1970s. In 1979, an ORGDP health standard was issued to establish a uniform method for controlling potential personnel exposures to and/or environmental releases of asbestos and to assure compliance with new Federal asbestos standards. In the late 1980s and early 1990s, the Plant initiated several independent asbestos characterization projects for both active and planned shutdown facilities (K-29, K-31, K-33). These projects helped determine the location, extent, and condition (friable or non-friable) of asbestos-containing building materials (ACBM) following requirements in EPA's 40 CFR Part 61 National Emission Standard for Hazardous Air Pollutants (NESHAPS).

Recommended response actions were developed for ORGDP facilities based upon ACBM classifications ranging from "immediate removal" to "no immediate action required." Before the 1970s, asbestos was used extensively as insulation against heat and resistance to corrosive chemicals. Asbestos was used in building materials (transite wall boards and ventilation ducting), floor tiles, water/steam and process pipe insulation, electrical panel gaskets/cable insulation, and friction brake shoes on electrical drive motors for compressors in gaseous diffusion plants. Asbestos was also used in cooling tower structures, ventilation duct curtains, and expansion joint coverings, and as blanket rolls by welders to protect against heat and weld splattering. Interviews conducted by the EH investigation team identified several instances of uncontrolled exposures to ACBMs among operators, maintenance mechanics, and welders who were not wearing respiratory protection up until the mid-1980s, when control procedures were implemented. No historical industrial hygiene data (air sampling or bulk sampling) for ORGDP was found. In 1990, the law firm of Provost and Umphrey conducted a screening survey of asbestos-related disease among the maintenance trades and some operators at ORGDP. The chest x-rays indicated asbestos-related fibrosis in 58 percent of the Oak Ridge workers who were tested. Although asbestos hazards were recognized in industry in the early 1970s, ORGDP's asbestos program was slow to develop.

Beryllium is a silver-gray metallic element used as pure metal, as beryllium-copper and other alloys, and as beryllium oxide. Beryllium is useful in manufacturing due to its strength, light weight, machinability, and relatively high melting point. The severity of health hazards resulting from even minimal contact with beryllium is only now being fully understood. Beryllium can enter the body through inhalation, skin absorption, skin wounds, and ingestion. The most serious health effects come from inhaling airborne insoluble particles that deposit in the lungs. Chronic beryllium disease (CBD), which occurs in one to six percent of exposed workers, has a latency period of up to 20 years and has no known cure. To date, two ORGDP workers have been diagnosed with CBD. An additional eight ORGDP workers have been identified as being sensitized to beryllium. A July 2000 study conducted by independent physicians identified an "unexpected incidence of beryllium sensitization" in the ORGDP workforce and recommended screening current and former workers for beryllium sensitization.

Urine analyses for beryllium were recorded as early as 1948, although there were no guidelines for interpreting results. OR published recommendations for the control of beryllium hazards in 1954. Regulated beryllium areas were established at ORGDP in 1989. Although there was restricted use of beryllium at ORGDP, there was more beryllium at ORGDP than at either Portsmouth or Paducah. During the late 1940s and early 1950s, the K-724 and K-725 buildings and surrounding yards were contaminated with beryllium during component machining, testing, and decontamination conducted during the nuclear propulsion aircraft project. Worker exposures to beryllium during this period are not known. However, building characterizations of K-724 in 1953 identified beryllium contamination throughout the building. It was estimated that at one time 13 grams of beryllium was contained in the ventilation duct system of the K-725 beryllium building. A report states that "a considerable amount of [beryllium] contamination was found on most equipment and in the building," and that some rooms were "quite heavily contaminated." Beryllium work was also conducted in several of the ORGDP laboratories. For example, in K-1004A, beryllium was used as a custom standard and in a beryllium spectrometric standard solution. Laboratory-scale quantities of reference standards containing 5 to 1,000 ppm of beryllium were used in K-1004B. In the late 1970s, beryllium was used in K-1004C as a substrate for plating. As late as 1990, work on beryllium samples was performed intermittently in the K-1004D metallurgical laboratory. Beryllium mirrors were assembled in K-1004L as part of the Strategic Defense Initiative. Both the K-1008C respiratory protective equipment cleaning facility and the K-1015 laundry facility cleaned or laundered clothing and PPE containing trace quantities of beryllium. From 1984 to 1990, beryllium temperature sensors called "hockey pucks" were filed and sanded for Sandia National Laboratories in the K-1035 instrument shop and K-1401 jig and fixture shop. Beryllium was machined on several other occasions in the K-1401 jig and fixture shop: during a two-month period in 1970, a two-week period in 1979, and a greater period around 1966 when over 250 test coupons were machined at the site. Other ORGDP locations for which beryllium use, storage, or disposal has been identified, or where beryllium could be present in small quantities (a few grams) or alloys, include K-1025, K-1036A, K-1037, K1058, K-1098E (heat treat facility), K-1220, K-1420, K-1419 (Central Neutralization Facility), K-1435 (TSCA incinerator), K-1417 (pond sludge handling facility), K-1407 B and C ponds, and the K-1070 A and B burial grounds.

Carbon tetrachloride and other chlorinated hydrocarbon solvents, such as methylene chloride and perchloroethene, had been used as degreasing solvents in the early decades. TCE, the dominant solvent at ORGDP until the 1980s, is described in a separate section below. Chlorinated hydrocarbons cause skin irritation due to the removal of skin oils, and they depress the central nervous system. **Carbon tetrachloride** is absorbed readily through the skin or lungs and produces kidney and liver damage on continued exposure. In the early years of the Plant, carbon tetrachloride was the solvent of choice for degreasing and cleaning operations, particularly for process motors in the ORGDP and K-27 buildings. The K-1030 electric shop, which was commissioned in 1946, used significant quantities of carbon tetrachloride in open tanks and vats to clean and refurbish more than 3,000 cascade motors in the K-25 building. To maintain a continuous volume of high-purity carbon tetrachloride, a carbon tetrachloride distillation process was installed in K-131. During the last half of 1949, over 16,000 gallons of carbon tetrachloride was processed in K-131. According to a report from the ORGDP industrial hygienist, a laborer washing windows in K-131 fell off a boatswain's chair due to the effects of inhaling carbon tetrachloride vapors from a distillation system vent. A Plant Quarterly Report notes that the widespread use of carbon tetrachloride was being curtailed in 1951 and that the policy would be documented in a Standard Practice Procedure (SPP) No. 7. However, during the same year (1951), in-place motor cleaning experiments using carbon tetrachloride commenced. In 1951, a 45-year-old ORGDP janitor died from spraying a carbon tetrachloride-based insecticide (Steamship Vaposector Fluid) in a locker room. By 1967, an ANSI standard on carbon tetrachloride was established (Z37.17-1967).

Many workers were also exposed to **methylene chloride**, another chlorinated hydrocarbon solvent. Methylene chloride depresses the central nervous system, and when metabolized in the lung produces carbon monoxide, which readily combines with blood hemoglobin and restricts the body's uptake of oxygen. Methylene chloride was used as a degreaser in a variety of shops and in the centrifuge buildings and laboratories. Methylene chloride was also used in the gas centrifuge process. A 1993 ORISE study of centrifuge workers noted that symptoms characteristic of exposure to methylene chloride, perchloroethene, and methyethylketone (e.g., numb and tingling limbs) were elevated in former centrifuge workers. In 1980, a worker complained of lightheadedness while degreasing a compressor with a solution containing 20 percent methylene chloride.

Another chlorinated hydrocarbon solvent, **perchloroethene (PCE),** is associated with both liver and kidney disease and was a common degreasing agent used in the Plant until the 1970s. PCE was used in the decontamination areas, instrument shops, and the centrifuge buildings. Workers recalled using PCE in K-1401 to degrease valves. Workers also complained that open, ventilated vats of PCE used in K-1420 would generate clouds of PCE in other building work areas. In general, former workers frequently asserted that they did not understand the hazards of these chemicals, seldom used respirators or gloves, and would frequently wash their hands in these cleaning solvents.

Chlorine, at atmospheric conditions, is a greenish-yellow, non-combustible gas having a density about 2.5 times that of air. Its disagreeable and suffocating odor, as well as the irritation it causes to the nose and throat, generally warns even unwary persons, thus enabling them to escape substantial exposure. Chlorine was used in water and sewage treatment systems as a disinfectant. Industrial hygiene records indicate routine sampling for chlorine. Raw water that supplied recirculating cooling water makeup was treated with chlorine to control algae and prevent bacteria growth, and then softened and clarified by treatment with lime and a coagulant to minimize scaling and sediment buildup. A corrosion inhibitor was then added to the processed raw water prior to distribution to recirculating cooling water systems. The use of gaseous chlorine from cylinders was discontinued in 1962 in favor of safer sodium hypochlorite, the latter derived from Y-12 waste solutions.

Chlorine trifluoride (ClF_3) is a powerful oxidizing agent, igniting many organic compounds on contact, and it reacts violently with water and hydrocarbons. At room temperature and pressure, chlorine trifluoride is a colorless gas having a density 3.14 times that of air. It is extremely corrosive to tissue, and any contact with skin or eyes will typically result in severe damage. The MAC for ClF_3 was one-tenth of that which was allowable for fluorine. PPE requirements for changing ClF_3 cylinders included respirators and face shields. Its reactivity led to its use as a fluorinating agent in ORGDP processes. Chlorine trifluoride was used in significant quantities offstream in the process buildings for such purposes as pre-treating converters. For example, ClF_3 was used in ORGDP in 1950 to unplug 153 stages that had been badly plugged from a power outage. A 1952 memorandum refers to a ClF_3 disposal system in K-29. Cylinders of ClF_3 were stored in K-631; an extensive piping system allowed ClF_3 to be distributed from K-631 to other buildings as needed. As late as July 1983, more than 900 lb of ClF_3 was stored on site. Chlorine trifluoride was also used in the ORGDP laboratories in the production of UF_6. Former workers recalled an explosion in the K-1004B laboratory when sample cylinders containing ClF_3 and HF came into contact with water. Another worker recalled an event in K-633 in the early 1970s when a ClF_3 release etched the glass windows within the building.

Chromium salts are irritating and destructive to tissue. Mists from electrolysis baths and plating baths cause dermatitis and damage to nasal membranes. Problems extend to the respiratory tract when dusts, fumes, or mists are inhaled. Because of the toxic nature of plating bath contents, disposal must be performed carefully to preclude serious environmental damage. Chromium compounds were used throughout the Plant's history in electroplating operations and as a corrosion inhibitor in recirculating water systems. While the long-term health effects are not well known, some workers have been exposed to chromium compounds from plating and transportation operations, as a result of the addition of dichromates to water systems, and during maintenance of those systems. In the mid-1950s and later, sodium dichromate was added in considerable quantities to the recirculating water system, primarily as an anti-corrosive agent. A report indicates that 100 pounds of sodium dichromate was added to the K-33 makeup water every 1-1/2 hours over a 33-hour period, and subsequently discarded into the Clinch River. Orocol, a Betz formulation of hexavalent chromate, zinc, and phosphate, was selected as the preferred corrosion inhibitor in the 1950s, replacing an earlier polyphosphate treatment. The K-1004-N and K-802 recirculating water systems were converted to a phosphate-based corrosion inhibitor in 1977 to address environmental concerns with chromate and zinc ion formulations; however, the other recirculating water systems were not converted. Studies at ORGDP have demonstrated the presence of hexavalent chromate in cooling tower drift and in the ground and vegetation near the cooling towers. One former worker asserted that an employee died from exposure to chromates, probably in the 1980s, although the EH investigation team did not find any confirmatory records. During interviews, two other former workers indicated that the process water and sanitary water systems had been cross-connected, resulting in workers possibly drinking chromated water. Given the level of configuration controls in effect at the ORGDP site over its history, it is possible that these errors occurred, and an investigation is currently in progress by ETTP personnel (see Section 4.5 for additional information).

Cyanide has a characteristic "bitter almonds" odor that can aid in diagnosis. However, a significant percent of the population is genetically incapable of detecting this odor. Therapeutic treatment must be initiated immediately to be life saving. At ORGDP, both cyanide salts and solutions have been used by instrument mechanics engaged in copper, nickel, and silver cyanide plating. Building K-1410 was the primary location in which electrolytic nickel plating operations were conducted from the late 1960s to 1979. A 1949 Quarterly Plant report notes that workers in the K-1004J laboratory had been exposed to cyanide as a result of silver-plating operations. During this period, environmental air tests for hydrogen cyanide were conducted, although the results were generally well below the cyanide MAC of 20 ppm. In 1987, a number of laboratory waste samples were analyzed for cyanide, and the results on some of the chemistry department worksheets indicated "high cyanide content." During interviews, several former laboratory workers indicated the presence and spillage of cyanide in K-1004C during the late 1980s. However, the EH investigation team did not identify the nature and disposition of these samples. Acetonitrile, which metabolizes to cyanide, was identified in small quantities (less than 5 gallons) in K-1004A, B, and D in 1986.

Since 1995, a number of health studies and investigations have been conducted at ORGDP in response to worker allegations of cyanide exposures. In 1996, NIOSH investigated reports from a group of ORGDP workers that they had developed a variety of health problems from exposure to cyanide at the Plant, as evidenced by elevated levels of cyanide and its metabolite thiocyanate in their blood and urine. NIOSH was not able to detect cyanides in air samples, nor was any occupational source of cyanide exposure identified. The results of the evaluation "show that employees at ORGDP are not occupationally exposed to hydrogen cyanide, cyanide salts, or a wide variety of other compounds that contain the cyanide ion." The workers have contested the results of the NIOSH study. In 1996, the University of Alabama performed air sampling and stated that "we have no information that indicates employee exposure in excess of recognized exposure limits" and concluded that "exposures to cyanide, if any, are quite low." A 1998 study of the TSCA incinerator conducted by the State of Tennessee concluded that "there are sick workers at the ETTP, and sick residents in its vicinity." But beyond that, "there was no unanimity on any topic." A July 2000 study of urinary thiocyanate levels in former ORGDP workers, conducted by independent physicians, indicated that in a comparison of ORGDP workers to an unexposed study group, thiocyanate levels were comparable for non-smokers, but the ORGDP workers who smoked exhibited higher concentrations of urinary thiocyanates than the study group.

Epoxy resins are the best-known type of adhesive in which a polymerization reaction is initiated by joining an epoxy monomer with a catalyst to produce a strong bonding agent. Epoxy resins can cause kidney and liver damage. Catalysts (usually amine compounds), which are used in the formation of an epoxy resin, can cause irritation and burns on contact. Catalysts also react violently with certain other chemicals, resulting in fumes that can damage the lung and cause serious burns. Accelerators make catalysts more effective and are known irritants. Accelerators, like some catalysts, are also sensitizers and are readily absorbed through the skin. Once in the body, accelerators depress the central nervous system. At ORGDP, the primary use of epoxy resins was in the centrifuge complex during the period 1960 to 1985. Over 30 buildings and laboratories at ORGDP were involved in some aspects of centrifuge development and operation, with principal facilities being the K-1004 laboratories (J, Q, R, S, T, and U), K-1052, and K-1200 series buildings. The major potential for chemical exposures occurred during manufacture of fiberglass centrifuge rotors and other centrifuge equipment during which workers were exposed to a variety of epoxy resins and other chemicals. Former centrifuge workers indicated that exposure to epoxy and chemical fumes was common, and the use of respiratory equipment was inconsistent. Workers also indicated that their exposures resulted in symptoms as previously described. ORISE, in 1989 (Phase I) and 1994 (Phase II), conducted studies on ORGDP centrifuge workers exposed to epoxy resins. Results from the Phase I study concluded that ORGDP centrifuge workers had greater than a seven-fold increase in risk for developing bladder cancer compared to the general population. The Phase II study did not confirm the increase in bladder cancer found in Phase I but identified an excess of temporary symptoms associated with solvents and resins. A description of ORGDP centrifuge operations is provided in Section 3.1.7.

Fluorine is a pale-yellow to greenish gas with a pungent, irritating odor. **Hydrogen fluoride**, or **hydrofluoric acid** (HF), is a colorless gas or fuming liquid with a strong, irritating odor. Exposure routes include inhalation, skin absorption (liquid), and skin and/or eye contact. Exposures can result in a variety of symptoms, ranging from irritation of mucous membranes to severe burns. The cascade process buildings (K-25, K-27, K-29, K-31, K-33, and K-1301 and 1302), feed plant (K-1131), decontamination facilities (K-1420), and maintenance buildings (K-1401) were primary sources for worker exposures to fluorine and **fluorine compounds (hydrofluoric acid and uranyl fluoride)**. Exposure pathways to HF at ORGDP involved the opening of normally closed systems that are used to process UF_6 or generate fluorine gas, leaks, or process upset events. UF_6 immediately breaks down into HF and UO_2F_2 when exposed to moisture in the air, so any leaks of UF_6 to the atmosphere result in HF exposures. Fluorine gas was used at ORGDP primarily for equipment conditioning, but lesser quantities were also used in chemical fluorination processes and in development facilities. In the early years, fluorine gas was generated in the K-1131 fluorine generating facility. Fluorine was also stored in significant quantities in tanks in K-1301 and K-1302 and was used extensively in the K-1131 feed manufacturing plant. There were other process and laboratory buildings that also exposed workers to fluorine and fluorine compounds.

During the late 1960s, some workers were exposed to **bromine pentafluoride** during UF_6 production. Overall, fluoride hazards were identified early in the Plant's history. The potential for exposure to fluorides at ORGDP was widespread and involved many workers. There are a number of documented overexposures, burns, and respiratory illnesses resulting from fluorine compounds. Medical records indicated that many workers were treated for burns from exposure to HF. In July 1955, nine workers were burned when a 200-pound HF cylinder ruptured. By 1959, one worker at the K-1131 fluorine generating facility had been burned by fluorine on at least ten occasions during his employment at ORGDP. Some of these workers did not seek medical attention, nor did Plant policy require reporting to the medical department. For decades, the industrial hygiene and safety group maintained airborne and biological monitoring programs for fluorides. The biological monitoring program consisted of routine and special urinalysis to determine fluoride content. Routine urine samples were submitted consistent with expected exposure frequency and concentrations, although typically on a monthly basis. In case of a probable exposure, special samples were obtained within a few hours after the event. However, few workers were recalled for urinary fluoride concentrations in excess of the fluoride recall standard of 1.5 mg/L (the Plant limit was 4 mg/L), except after suspected material releases. A 1951 Plant Quarterly Report attributed 78 percent of the entire Plant's positive readings on urinary fluorides to K-1131. Short-term air grab samples, area air samples, and personal breathing zone samples have also been used to determine HF concentrations during work activities and to determine respiratory protection requirements. During the late 1940s, fluorine and HF concentrations above the MACs of 1 ppm for fluorine and 3 ppm for HF were evident in 20 percent of the routine air samples. A 1962 study performed by the ORGDP medical director involved 61 workers during the period of 1952 through 1959 who had worked in a fluorine-contaminated environment for a significant portion of their work history. Fluorine air concentrations in their work areas ranged from 0 to 24.7 ppm, but averaged 0.9 ppm. There was no evidence of increased respiratory complaints or respiratory disease in the workers. The study concluded that "there was no impairment to health of people working in fluorine concentrations probably in excess of 0.1 ppm." This conclusion was reaffirmed in a 1977 follow-on study by the new ORGDP medical director, recognizing that the previous study was based on a limited sampling of workers. However, there is sufficient evidence from interviews with former workers and from historical and medical records to indicate that a number of workers were subjected to fluorine concentrations significantly greater than 0.1 ppm and did experience short-term health effects.

Calcium fluoride is a white crystalline powder used as an additive to products in the metal, ceramic, and glass industries. A mild irritant to the skin, eyes, and respiratory system, it is practically insoluble in water and therefore has low toxicity if ingested. Prolonged absorption of fluorine compounds from dust or vapors may cause mottling of teeth, brittle bones, calcified ligaments, and joint stiffness. The TLV for fluorine compounds (as dust) is 2.5 mg/m^3 as a time-weighted average.

Fungicides and biocides were used at ORGDP for preserving recirculating cooling water cooling tower wood and preventing algae growth. Fungicides and biocides can enter the body through ingestion, inhalation, and absorption pathways, with inhalation and skin absorption being the primary concerns. Health effects vary from minor headaches and nausea to debilitating conditions of the central nervous system. Originally, the cooling towers were constructed of untreated redwood. After years of operation that leached the natural fungal resistance from the redwood, fungal attack and significant structural damage were recognized in 1950. ORGDP then initiated a program of periodic inspections and, where needed, refurbishment and fungicide treatment of cooling tower wood. Records reviewed by the team identified only two in-situ cooling tower treatments utilized at ORGDP. Both were used during the period from the late 1950s to the mid-1970s.

The "Mar-treat" or double-diffusion process was initially used only on the cross-flow cooling towers because of the accessibility of the wood. The process proved very effective and involved isolating a cooling tower section, installing plastic catch basins and recirculating pumps at the bottom of the tower, and then circulating three separate solutions over the wood until each was adequately absorbed. The first solution contained arsenic acid and zinc sulfate; the second contained sodium chromate that joined with the earlier solution to form several insoluble compounds toxic to fungus; and the third contained sodium carbonate to "fix" the compounds in place. Because of the equipment needed to "Mar-treat" a tower and the availability of staff experienced in the process, contractors were utilized to perform these treatments.

The second process, called "steam sterilization," was initially used on counter-flow cooling towers. It involved isolating and enclosing a section of the cooling tower, instrumenting the section with temperature sensors, flooding the section with steam to raise and hold the temperature for a set amount of time to kill the fungal colonies, and then flooding the section with a vaporized insoluble pentachlorophenol compound called "Steam Chem" using steam as the carrier. Until the "Mar-treat" process was adapted for application to counter-flow cooling towers, the treatment of these towers using "Steam Chem" was performed by ORGDP staff. A report documented requirements for hard hats, safety shoes, and eye protection and noted the use of Army assault masks and rubber gloves while handling the dry chemical, followed by showering and donning clean clothes. Reportedly, no one was allowed on the tower during chemical application, and downwind activities were controlled. Finally, only rubber gloves were reportedly needed when dismantling the enclosures and temporary steam piping. A 1971 maintenance procedure required employees handling the chemical to wear splash goggles over safety glasses, respirators, long-sleeved heavy rubber gloves, long-sleeved coveralls, and coverings over exposed body areas, such as a towel wrapped around the neck.

Reviews of records and discussions with long-time employees did not identify any evidence of chemical exposure monitoring while spraying fungicides in the cooling towers. Records from 1981 demonstrate that in-situ pneumatic fungicide spraying of Betz F-14 (sodium pentachlorophenate) or TBTO (tri-butyl-tinoxide) was being considered; however, the EH investigation team found no clear evidence that this took place. Records did document that the makeup water to the K-1004-N cooling tower was treated with Dearborne 321 and Zimmite Chemtrol 19 biocides, solutions containing pentachlorophenols. Cooling tower signage, employee bulletins, and training materials from as early as 1983 required respiratory protection against the possible presence of bacteria while working on top of an operating tower and within heavy mist. The principal concern was **Legionnaire's disease bacteria (LDB)**, a naturally occurring bacterium. The training information also reminded employees of the potential need for additional hazards assessments and respiratory protection when disturbing treated wood. Records from 1989 describe preparations for characterizing the cooling tower in preparation for dismantlement and disposal. The minimum required safety equipment for sampling activities included full-face respirators, disposable coveralls, safety glasses, chemical-resistant gloves, and safety shoes. Industrial hygiene staff were also required to monitor airborne contaminants during sampling activities. Among the hazards listed as possibly still present were arsenic, pentachlorophenate, dioxin, and furans from earlier fungicide and biocide treatments.

Lithium is intensely corrosive and may produce burns on the skin from the formation of the hydroxides. Like most toxic metals, chronic exposure to lithium compounds at elevated levels can result in impaired functioning of the kidneys, changes in blood pressure and blood volume, and neural and hormonal effects. From 1974 to August 1994, lithium compounds were periodically shipped from the Y-12 Plant to ORGDP due to Y-12's lack of storage space. Lithium chloride ($LiCl$) and lithium hydroxide monohydrate ($LiOH \cdot H_2O$) was stored in its original fiberboard containers in the K-25 building vaults for 15 to 20 years, and several of these containers were deteriorating due to moisture. The vaults have no temperature or humidity controls. In the early 1980s, the fiberboard containers were overpacked in 80-gallon polyethylene-lined steel drums. In 1995, management decided to discontinue using K-25 as a storage facility. At that time, 55,470 drums of lithium compounds were stored in 17 vaults at the K-25 building. Starting in 1996, most of these drums were removed from the K-25 vaults, except for two vaults where some lithium drums continue to be stored. Plans are to remove these drums by 2003, before demolition of K-25. The remaining lithium compound drums in the K-25 vaults receive monthly surveillance and maintenance inspections, and approximately 50 drums are overpacked annually. Interviews conducted by the EH investigation team indicated that some workers overpacking the deteriorating drums did not wear respiratory protection. A welder in the middle 1970s reportedly stopped a cutting job because the torch was stirring up lithium powder on the floor near deteriorating drums in K-25. Industrial hygiene checked the potential hazard and indicated that the dust would be harmful only to a pregnant female. The welder was asked to leave the job and allow another worker to complete it. In 1989, lithium hydride (LiH) log machining equipment was installed in Building K-1401 to prepare small test specimens for measurement of physical properties, such as tensile and compressive strengths. LiH reacts strongly with water and oxygen to form $LiOH$ and lithium oxide, generating heat and hydrogen that in turn can burn or explode if ignited in the presence of air. The machining was performed dry inside a glovebox purged with nitrogen. A meticulous safety procedure was instituted to receive the LiH logs from the Y-12 Plant, machine the specimens, and return the products and the wastage to the Y-12 Plant.

Mercury exists as an element (metallic) and as inorganic and organic compounds. Early symptoms of mercury poisoning include salivation and tenderness of the gums. Mercury vapor can reach the brain cells, where it is oxidized to produce toxic effects. The major effects of chronic exposure to mercury vapor are on the central nervous system, resulting in increased excitability and tremors. Chronic elemental mercury symptoms are slow to develop and difficult to diagnose. Inorganic mercury salts, such as mercuric chloride, often cause skin problems and can result in extensive kidney damage. Organic mercurials, such as methyl mercury, can cause severe birth defects or mental retardation. Health effects of mercury were known as early as the 1940s. There were many uses and potential worker exposures to mercury from the early days of operation and throughout the Plant's history. Several operations and maintenance activities involved mercury handling, purification, and recovery. Mercury usage and handling, throughout ORGDP, was common in manometers, switches, mass spectrometers, mercury diffusion pumps, mercury traps, and laboratory operations. Process buildings contained thousands of manometers, thermometers, and switches containing mercury. The most significant mercury operation at ORGDP was the distillation and recovery of elemental mercury in Buildings K-1303 and K-1420. From 1948 to 1956, mercury recovery operations were performed in Building K-1303. From 1956 to 1980, operations in the K-1420 ground floor mercury recovery room including cleaning and recovering mercury from wastes using a washing and distillation process. Mercury was also stored and handled in the instrument development laboratory in the north end of Building K-1401, in numerous other buildings (e.g., K-725, K-1035, and K-1024), and in most of the ORGDP laboratories. As early as 1946, ORGDP workers were being monitored for mercury exposure by the Plant industrial hygiene department. By 1947, exposure limits of 0.1 mg/m^3 (in air) and 0.1 to 0.3 mg/L (in urine) had been established at ORGDP. (The current ACGIH limit for airborne concentrations of inorganic mercury, including metallic mercury, is 0.025 mg/m^3 for an eight-hour time-weighted average.) Mercury spills and worker exposures to mercury were recurrent issues throughout the history of the Plant. Urinalysis data in the 1940s, 1950s, and 1960s suggest that mercury exposures were a continual problem at ORGDP. An accident in K-1024 in 1947 resulted in serious contamination (3.2 mg/m^3) of some rooms. In 1948, the safety and inspection division issued a safety bulletin warning that the use of standard vacuum cleaners to clean up mercury spills had resulted in airborne mercury above acceptable levels. Later recommendations suggested using hopcalite filters in mercury vacuum cleaners. In 1949, 7.8 percent of the 380 air samples for mercury vapor were reported to have exceeded MACs. A Plant Quarterly Report in 1951 notes an “unusual increase in positive air and urinary mercury analysis from widely scattered areas in the plant” and records that 45 of the 302 mercury air samples exceeded MACs. In the early decades, respirators were not routinely required for some mercury cleanup activities. As late as 1983, procedures for reporting, cleaning up, and disposing of mercury spills were being revised. Mercury usage at ORGDP is described in more detail in Section 3.1.4.

Nickel metal is a hard, silvery solid with a high melting point. Nickel carbonyl, a volatile liquid and a very toxic gas, is the most acutely toxic nickel compound known, causing immediate poisoning, hemorrhagic pneumonia, and delayed lung effects. Nickel-plating workers can suffer from dermatitis caused by skin contact with nickel salts. Nickel compounds also can cause chronic eczema. Some individuals can become sensitized to nickel, and once sensitized, they respond to contact with nickel alloys. In industry, nickel-plating workers and welders exposed to various nickel compounds have developed allergic lung reactions, such as asthma; loss of the sense of smell; and severe nasal injuries, such as perforated septa and chronic sinus infections. Increased susceptibility to respiratory infections is also possible. At ORGDP, nickel-related operations were performed in several areas of the Plant. Worker exposure to nickel was possible during welding, cutting, or grinding on nickel-containing components; nickel spraying and plating operations (K-1004C); and handling of scrap materials containing nickel. Nickel plating, via both electrolytic and electroplating processes, was conducted in K-1410 and K-1420 after 1954. However, the most significant exposure to nickel powder at ORGDP was in the manufacture of barrier material in the K-1037 barrier plant. At the gaseous diffusion plants, elemental nickel formed into a porous membrane (barrier) is the basic component used to separate uranium isotopes. All barriers used in the three gaseous diffusion plants were manufactured at ORGDP in Building K-1037 between 1945 and 1982. Workers were exposed to nickel dusts, particularly in the blending tower. Current OSHA PELs for elemental nickel and nickel carbonyl are 1 mg/m^3 and 0.007 mg/m^3, respectively. Limits are based on an eight-hour time-weighted average. NIOSH recommends comparable or lower limits of 0.015 mg/m^3 for elemental nickel and 0.007 mg/m^3 for nickel carbonyl. In 1950, Plant limits for nickel were set at 0.5 mg/m^3 (as a guide). The recollection of a number of former workers who had worked in K-1037 was that during the period of 1950 through the early 1970s, the facility was laden with nickel dust that resulted in respiratory illnesses, skin rashes, sinus irritation, and coughing up of black phlegm. Furthermore, until the early 1970s, many workers in the barrier plant worked in their personal clothing and wore their nickel-contaminated clothing home. Although respirators were provided in some areas, workers often did not wear them, or wore them improperly, since workers did not receive respirator fit tests until the mid to late 1970s. A number of workers indicated that they were not informed of the hazards of working with nickel. Although enclosures and other engineering controls were provided in the blend towers to reduce the concentration of airborne nickel, workers indicated that the enclosures impeded production and often were not used. By 1977, ventilation system improvements in the barrier plant were completed. It was expected that these modifications would reduce personnel exposures to less than the OSHA standard of 1 mg/m^3 but would not meet the NIOSH recommendation of 0.015 mg/m^3.

Industrial hygiene personnel took frequent air samples throughout the period of operation of the barrier plant. From the 1950s through the 1970s, nickel workers were also in a urinalysis program. The average airborne nickel concentrations reported by Union Carbide between 1948 and 1973 were between 1.5 and 2 mg/m^3. However, some industrial hygiene records identify barrier plant nickel concentrations in the early years that far exceeded those averages. For example, in 1952, air samples in the range of 187 to 303 mg/m^3 were recorded by ORGDP industrial hygiene at the pulverizer booth and 39 mg/m^3 at the blending area. The industrial hygienist also recorded that workers in the blending area were not wearing respirators. One former worker indicated that at times "the nickel dust was so thick you could not see a man standing at the wall." Regarding long-term health effects, ORAU studied and reported on the mortality of nickel workers at the barrier plant in 1978 and 1984. ORAU concluded that there was no evidence of increased mortality due to lung cancers or nasal sinus cancers in nickel workers.

Exposures to **nickel carbonyl** ($NiCO_4$) were also in excess of the allowable plant limits. In 1952, the Plant was aware that nickel carbonyl, which was used primarily in small quantities in the laboratories, was known to cause cancer of the lungs. In the 1950s, the Plant industrial hygienist also identified nickel carbonyl in the K-1037C smelter. As a result, a limit of 1 ppm was established, and chest x-rays of affected workers were required every three months. During the late 1940s, $NiCO_4$ was also used in K-1004B and C, in benchtop quantities, for plating components. Nickel carbonyl concentrations in excess of Plant limits were identified in the barrier plant and laboratories. In one case, a spill of nickel carbonyl in 1962 outside a laboratory hood in K-1004D exceeded the limit by a factor of 1,000. Concentrations of nickel carbonyl outside the building at Avenue D also exceeded limits. A nickel carbonyl release in 1961 in K-1413 resulted in overexposure of six workers.

Overall, there are clear indications that workers in the barrier plant were exposed to concentrations of nickel powder and nickel carbonyl in excess of Plant limits. PPE (clothing and respirators) was issued in some cases, but only occasionally worn. Although there are documented cases of respiratory illnesses and dermatitis in workers in the barrier plant, the mortality of these nickel workers was no greater than that of the unexposed population.

Polychlorinated biphenyls (PCBs) are a colorless to lightly colored, viscous liquid with a mild odor. The critical pathways of exposure are inhalation, ingestion, and absorption. When humans are exposed, PCBs can affect the skin, liver, central nervous system, and respiratory system. Throughout industry, including ORGDP, the hazards and controls for working with PCBs were not known until the 1970s. PCB-based oils were used at ORGDP in many power transformers for their chemical stability, fire resistance, and dielectric properties. Until the early 1970s, these oils were periodically filtered and de-sludged, with the resulting filtrate and contaminated filter material disposed of on site. Several interviewees described dumping PCB-laced waste oil alongside the railroad tracks. PCB oils were also used in synchronous condenser grounding transformers, potential transformers, ground reactors, oil circuit breakers, oil-filled capacitors, light ballasts, ventilation duct gaskets, and certain high temperature grease. Records indicate at least two transformer explosions and several electrical equipment failures that likely released PCBs to the environment. PCB contamination was also identified in electrical cables and wires, on equipment and surfaces exposed to leaks, and on components painted with PCB-contaminated paint. Procedures for handling, storing, and disposing of PCB-contaminated oils were in place as early as 1972, and procedures in 1975 recommended avoiding exposure to PCB and specified the use of non-absorbent gloves, aprons, and eye protection during its handling. Gas masks or self-contained breathing apparatus was required when exposures to high vapor concentrations were possible. Otherwise, respirators were not deemed necessary, except when the PCBs were heated. By 1989, procedures required wearing of clothing, including gloves, aprons, and boots, impervious to PCBs when individuals might be exposed to PCBs. Respiratory protection was then mandatory, and full-face respirators or self-contained breathing apparatus was recommended while handling the material. In the mid- to late 1970s, ORGDP replaced many PCB-filled transformers with dry or mineral oil-filled designs. In the 1980s, many of the PCB-filled power capacitors were removed and disposed of. In the late 1980s, the process building ventilation duct joint gaskets were found to contain PCBs, impregnated during manufacturing. This contamination was being leached from the gaskets by process motor lubricating oil that had collected in the ventilation ducts, which then dripped on electrical cables, equipment, and the floor.

In the late 1980s and early 1990s, ORGDP installed troughs on leaking ventilation duct joints to collect PCB-contaminated oil, prevent the spread of contamination, and assure appropriate disposal.

Trichloroethene (TCE) is a colorless liquid with a chloroform-like odor that is used as an industrial degreaser. TCE is a mild irritant to the respiratory tract and the skin, and is considered a potential carcinogen based on animal studies. Critical exposure pathways are inhalation, ingestion, and skin or eye contact. TCE concentrates in the respiratory system, heart, liver, kidneys, central nervous system, and skin. At ORGDP, use of TCE as an equipment degreaser was reported as early as 1946 at degreasing stations in K-1401, the line recording stations in K-25 and K-27, the cold traps in K-1301, and the instrument repair shop in K-1024. An air contaminant study published in 1946 by the Carbide and Carbon Chemicals Corporation found that for TCE the MAC of 100 ppm was exceeded 70 to 90 percent of the time while sampling in K-1401, and 27 percent of the time in K-25 and K-27. Industrial hygiene air sampling reports in 1960 recorded TCE concentrations greater than 600 ppm for equipment degreasing operations and over 450 ppm for maintenance work in the pits of the Central Cleaning Area. Often respirators were not worn.

Uranium radiation hazards are discussed in the previous section, "Radiological Hazards." As a heavy metal, uranium is toxic and can damage the kidney. Both solubility and enrichment determine the toxic chemical effects. Historically, the health physics group at ORGDP was responsible for addressing both the radio-toxicological and the chemical toxicological exposures of workers to uranium. Workers in the ORGDP process and feed materials buildings, and workers performing maintenance, cleaning, or inspections of process components in other buildings, were exposed to uranium compounds and dusts and occasional accidental process gas (UF_6) releases. Upon release to the atmosphere, UF_6 is hydrolyzed to uranyl fluoride (UO_2F_2) and hydrofluoric acid; as a result, its toxicity is a combination of both an irritant gas and a heavy metal. Nine process gas releases were reported in the third quarter of 1949 alone, one of which occurred in K-631 when a tails cylinder connection broke, sending 25 workers to the dispensary. A program for analysis of urine samples for uranium was evident at ORGDP as early as 1948, with a number of workers typically exceeding the MAC for uranium. A 1970 Union Carbide Corporation study of uranium workers at ORGDP and the Y-12 Plant concluded that uranium workers at these plants "had a more favorable mortality experience than a population of non-uranium workers employed at the same facilities during the same time." In addition, the study noted that both uranium and non-uranium workers had a more favorable rate than predicted based on tables supplied by the Bureau of Vital Statistics.

Welding gases have always been a common and continuing concern at ORGDP, and there is a wide variation in the degree to which workers experienced this hazard on the job. The hazard to the eyes and skin due to sparks and fragments of hot metal were well recognized, and welders were usually well protected with face masks, gloves, and other protective clothing, including flame-retardant coveralls in later years. However, a review of medical records identified a number of cases in which welders and co-located workers were burned. The dangers from chemical exposure were not as well recognized. The type of fumes from welding depends on the metal being welded and the type of welding rod used. Arc welding and plasma cutting produce irritating and oxidizing ozone gas. Degreasing fluids can remain on the metal, resulting in additional vapors. In addition, paints, grease, and other coatings may be burned and volatilized. ORGDP industrial hygienists have analyzed welding fumes since the 1950s. During 1947, traces of phosgene were identified in electric welding smoke, although efforts to locate the source of phosgene were unsuccessful. In 1959, elevated levels of phosgene were detected in the breathing zone of welders. From 1945 through 1947, workers were also exposed to phosgene gas through a project to inspect chemical warfare service cylinders previously containing phosgene. Over 458 cylinders were examined in 1947, 5 percent of which showed phosgene to be present. In 1991, two subcontractor workers who engaged in oxyacetylene cutting and welding operations in K-1037 became ill, which triggered a Type B investigation. The Type B investigation report concluded that the hazards associated with this welding project were not properly identified or adequately mitigated.

Physical, Biological, and Common Industrial Hazards

Throughout the Plant's history, workers at ORGDP were subjected to variety of physical, biological, and common industrial hazards. Some of these hazards were not well known either in industry or at ORGDP until the 1970s or later. Line management generally made a conscientious effort to identify, quantify, and control these hazards commensurate with the understanding of those hazards at the time. However, there are also numerous documented cases of inadequate procedures and procedural non-compliance by workers, as well as injuries and illnesses resulting from physical, biological, and industrial hazards.

Dusts are small solid particles created by breaking up larger particles through processes such as grinding, drilling, or crushing. Typical airborne industrial dusts, in forms ranging from metallic fumes to metal grindings, have particle sizes from 0.1 to 100 microns in diameter. When inhaled into the lungs, ingested, or exposed to the skin, metallic dusts such as copper, nickel, uranium, and aluminum may cause acute or chronic health conditions. These may include lung disease, organ changes, central nervous system abnormalities, and dermatitis. Silica or beryllium dust particles, when inhaled into the lung from high and/or long-term exposures, may cause scarring of the lung tissue (fibrosis). This effect usually leads to a loss of functional capacity and increases the susceptibility to other lung diseases, such as cancer. Symptoms include shortness of breath, chest pains, fatigue, and lack of oxygen. The ORGDP site has implemented continuing dust sampling programs since the late 1940s for silica, nickel, copper, and beryllium. As early as 1948, site buildings, such as K-1401, were being sampled for silica dust, and a MAC of 5 million particles per cubic foot limit was set. Interviews with former workers, and industrial hygiene air sampling records, indicated that a number of Plant buildings were excessively dusty.

Explosions and fires were a continual threat to operations and worker safety throughout the history of the Plant. Numerous large fires were reported during the 1940s and 1950s, typically initiated by welding and cutting torch work, laboratory experiments, and cigarette disposal. Injuries due to fire, however, were infrequent. Some explosions were reported as a result of laboratory experiments, such as the 1950 explosion of Miller's Fluorinated Lubricant oil when contacted with fluorides. Fire loss ratios were reported monthly in the early decades.

Mold and indoor air quality issues began to be evaluated at ORGDP as occupational health concerns as early as the 1970s. With the discovery of Legionnaire's disease in 1976, entrainment of airborne bacteria and mold in ventilation systems began to be recognized as a potential health concern. In the 1980s, techniques for sampling airborne mold and bacteria were developed and used, and these techniques continue to be refined today. Although guidelines were established in the 1990s for indoor air quality parameters, there are no established TLVs or PELs indicating levels of mold and bacteria that can be judged to be "safe" or "unsafe." During the 1990s, a series of occupationally related respiratory illnesses were linked to workers in the K-25 building, which had been shut down since the mid-1960s. An OR "for-cause review" was initiated in 1998, and a respiratory policy for mold soon followed. More than a dozen former workers who were interviewed complained about respiratory illnesses that they believe are attributable to mold conditions in their workplaces (primarily in the K-25 building) and asserted that these conditions existed since the mid-1980s.

Occupational noise is one of the most significant industrial hazards. Overexposure to noise results in impaired hearing or hearing loss in thousands of workers annually. During the 1940s, excessive noise levels were identified and monitored in numerous ORGDP buildings, including the process buildings, the barrier plant, the powerhouse, and the K-25 laboratories. During the late 1940s, a 90-decibel (dB) noise level limit was established, and sound level surveys and measurements of sound frequency distributions were performed by industrial hygiene personnel. A 1948 quarterly report indicated that audiometric testing for hearing loss had been instituted as part of the industrial health examinations, and that arrangements had been initiated to "provide ear protection equipment" (i.e., the American Medical Association ear plug with lubricant). In 1951, the ORGDP medical director discussed the heath effects of excessive noise with Plant managers and noted that noise levels in the K-25, K-27, and K-29 buildings on the operating floor ranged from 102 to 110 dB. The OSHA occupational noise standard was adopted in 1975, and in 1977 OR established a policy that all noise sources exceeding 84 dBA must be identified and monitored. By 1981, DOE and ORGDP noise standards had been revised to state that no individual shall be exposed to noise levels in excess of 80 dBA without proper hearing protection, which is more conservative than today's OSHA standards. Many former workers recalled exposure to excessive noise, particularly in the K-31 and K-33 process buildings, and often without hearing protection. Some indicated that ear protectors were available but were not required. A common practice in the early decades was for workers to keep earplugs in their pocket for use, but only after a headache developed.

Physical hazards, which were present at ORGDP from the commencement of Plant construction in 1943 through 1997, resulted in the majority of injuries and deaths to Plant workers. Common physical hazards included the use and maintenance of energized equipment, hoisting and rigging, heavy equipment operations, elevated work, vehicle operation, scaffolding and ladders, machine guarding, and slips, trips and falls. Historic documentation reflects a number of fatalities at the ORGDP in the early years, including auto accidents, falls during construction, electrocutions, and several crushing fatalities involving heavy equipment and trains. After major construction activities slowed in the 1950s, worker fatalities and serious injuries from physical hazards decreased significantly. In addition, a review of medical records identified many back injuries and muscle strains and sprains throughout the Plant's history. Many of the early promotion and education programs were directed toward mitigating physical hazards. For example, a 1950 Safety Department Progress Report noted that the Plant Safety Committee's emphasis was on correcting "unsafe conditions and acts" through practical demonstrations (e.g., ladder safety), safety bulletins on the use of hand tools, and safety films.

Temperature extremes, particularly heat stress, posed a concern in most of the ORGDP process buildings, the barrier plant, and the feed materials buildings. A variety of heat stress disorders can be attributed to overexposure to heat, including heat cramps, heat stress, and heat stroke, which can be fatal. In 1957, an internal memorandum documented 13 reports on high-temperature working conditions in ORGDP process buildings, and further noted that considerable expense and effort had been devoted to alleviating personnel heat stress in these buildings. By 1969, the World Health Organization (WHO) had established criteria for working in hot environments. In 1971, ACGIH issued their heat stress criteria based on the WHO report, and in 1972 NIOSH issued to OSHA a recommended standard of 79 F wet bulb globe thermometer for worker protection. An ORGDP study conducted shortly thereafter concluded that "in mid-summer the environmental conditions on the cell floors are far in excess of this value." By 1972, a Four-Plant Heat Stress Committee was meeting at regular intervals. A number of former workers cited heat stress as a significant concern in their work environment, indicating that cell floor operating temperatures exceeded 100 F and that temperatures exceeding 130 F could be reached at the building cranes located near the roofs of the buildings or in the escape alleys of K-25 and K-27.

APPENDIX B
PRINCIPAL ACTIVITY EVALUATION SUMMARY

Table B-1 outlines the principal activities conducted at ORGDP between 1943 and 1997, and provides a summary assessment of the hazards that may have been encountered, the controls available and generally used to mitigate the hazards, and the effectiveness of the controls when implemented. It is likely that numerous other hazardous tasks were performed for which data were not available during this investigation and accordingly, are not represented in Table B-1. Abbreviations used are defined below.

Abbreviations Used in Table B-1:

Acids	Includes one or more of: acetic, citric, hydrochloric, nitric, sulfuric acids
Bioassay	Includes urinalysis and/or in-vivo lung counting
CIP	Cascade Improvement Program
CUP	Cascade Upgrade (or Uprating) Program
HF	Hydrogen Fluoride
NC	Risk of nuclear criticality
NDA	Nondestructive Analysis
Np	Neptunium
PCB	Polychlorinated Biphenyl
PPE	Personal Protective Equipment (includes one or more of: respirator, shoes, gloves, caps, eye protection, ear plugs, and contamination clothing)
Pu	Plutonium
RAD	Includes one or more of: alpha, beta, gamma radiation
Solvents	Includes one or more of: acetone, benzene, carbon tetrachloride, methylene chloride, perchloroethene (PCE), trichloroethene (TCE)
STF	Slips, trips, and falls (common industrial accidents)
Tc-99	Technetium-99
Th	Thorium
TLD	Thermoluminescent Dosimeter
TRU	Transuranic

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Ash handling	K-1131, K-1410, K-1413, K-1420	RAD; UF_6, HF, and fluorine gases; dust containing uranium and concentrated daughter products, fission products, and TRU; noise	Film badge or TLD, PPE, bioassay, stay time, worker rotation, ambient air flow	Moderately effective when used correctly	1951-1985
Ash crushing	K-1231	RAD, uranium and concentrated daughter products, TRU	Film badge or TLD, PPE, stay time, worker rotation, bioassay, ambient air flow	Moderately effective when used correctly	1951-1961
Ash storage and de-smoking	K-1131, K-1031, K-1410	RAD; UF_6, HF, and fluorine gases; dust containing uranium and concentrated daughter products, fission products, and TRU; noise	Film badge or TLD, PPE, stay time, worker rotation, bioassay, ambient air flow	Moderately effective for workers when used correctly, ineffective for passersby and the environment	1950-1952 (K-1131) 1952-1961 (Outdoors east of K-1031)
Baghouse filter cleaning and changes	All process buildings	RAD, UF_4, TRU, uranium dust, concentrated daughter products	Film badge or TLD, PPE, bioassay, ambient air flow	Moderately effective when used correctly	1945-1984
Barrier production	K-1037	Nickel powder dust	PPE, ventilation	Moderately effective when used correctly	1945-1982
Bottle smashing	K-900	Solvents, anhydrous ether, isopropyl ether	PPE, ventilation	Moderately effective when used correctly	1980-1988
Building access (to perform various duties, such as deliveries)	All buildings	See full range of hazards described for all Plant facilities	Film badge or TLD, PPE, bioassay, housekeeping, postings	Moderately effective when used correctly	1943-1997
Burial of classified and contaminated materials	K-1070-B, K-1070-C/D	RAD, UF_6, nickel carbonyl, asbestos, PCBs, mercury, lead, beryllium, copper, uranium	Film badge or TLD, PPE, stay time, bioassay	Effective when used correctly	1950s-1974 (K-1070-B) 1974-1976

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Burning operations	K-1064, K-1085, firehouse burn area	RAD, lead paints, solvents, PCBs, organic wastes	Film badge or TLD, PPE, bioassay	Ineffective	1944-1960s
Can and drum crushing and drum deheading	K-1064G	RAD, solvents, UO_3, TRU, Tc-99	Film badge or TLD, PPE, bioassay	Effective when used correctly	1970-1979
Carpentry	Cooling towers, process and other buildings	RAD, asbestos, arsenic, fungicides, acids, solvents, chromates, sodium silica, formaldehyde, nickel powder, noise, STF, Legionnaire's Disease bacteria	Unknown	Unknown	1943-1997
Cascade operations	K-25, K-27, K-29, K-31, K-33, K-131, K-1131	RAD, UF_6, fluorine, TRU, Tc-99, heat, asbestos, solvents, moving equipment, noise, mold (after 1975)	Film badge or TLD, PPE, bioassay	Moderately effective when used correctly	1944-1997
Classified materials handling	K-1006, K-1231, K-1232, K-1233	Dust, caustics, solvents, acids	Film badge or TLD, PPE, bioassay	Moderately effective when used correctly	1958-1997
Collection of gas cylinders (for purging)	Lambert's Quarry, Blair Road Quarry	Phosgene gas, solvents, chlorine trifluoride	Unknown	Unknown	1950s
Collection of uranium oxide powder from calciner	K-131, K-1303, K-1410, K-1420	Insoluble airborne uranium, TRU	Film badge or TLD, PPE, bioassay	Moderately effective when used correctly	1954-1984
Conversion of uranium oxides to UF_6	K-1004J, K-1131, K-1301, K-1405-6, K-1413, K-1420	RAD; uranium and transuranics; burns from HF and F_2	Film badge or TLD, PPE, bioassay, ventilation	Moderately effective when used correctly	1945-1985

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Crane operation	All process buildings	RAD, HF, UO_2F_2, heat	Film badge or TLD, PPE, bioassay	Effective when used correctly	1943-1997
Cross connection of sanitary water with recirculating, cooling, fire, or non-potable water systems	Potentially any building	RAD, water treatment chemicals (biocides and corrosion inhibitors)	Administrative restrictions on taps to sanitary water; removal of cross-connections or installation of additional backflow preventers and anti-siphon devices in 1980s	Moderately effective when used prior to 1980s; effective when used correctly after upgrades	1943-1997
Cutting or welding fluorinated hydrocarbon coolant pipe	Process buildings, K-1401, K-1420	Phosgene, hydrogen chloride, high temperature surfaces, welding gases	PPE, ventilation, coolant evacuation procedures	Effective when used correctly	1944-1997
Cylinder destruction	K-901-A pond, K-895	RAD, uranium daughters, HF, UF_6, high temperature surfaces	Unknown	Unknown	1960s (K-901-A pond) 1965-1975 (K-895)
Cylinder heel cleaning	K-1410, K-1420	RAD, UF_6, TRU, NC, solvents, concentrated fission and daughter products, caustic chemicals	Film badge or TLD, PPE, bioassay, ambient air flow, cylinder net weight determination, enclosed cleaning system	Moderately effective when used correctly	1943-1984
De-blading of compressor rotor and stator	K-1401, K-1420	RAD, UF_6, HF, UO_2F_2, TRU, Tc-99, fission and uranium daughter products, noise	Film badge or TLD, PPE, bioassay, UF_6 Negative procedure, ventilation	Moderately effective when used correctly	1945-1997
Decladding and fluorination of unirradiated reactor fuel	K-1413	RAD, uranium, acids, and BrF_5	Film badge or TLD, PPE, bioassay	Moderately effective when used correctly	Late 1960s
Decontamination of equipment	Process buildings, K-1024, K-1035,	RAD, UF_6, U_3O_8, HF, UO_2F_2, TRU, NC, PCBs, oralloy, tuballoy,	Film badge or TLD, PPE, stay time, bioassay, ventilation,	Moderately effective when used correctly	1945-1990s

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Decontamination of equipment (continued)	K-1231, K-1303, K-1401, K-1410, K-1420	acids, solvents, uranium daughter and fission products, asbestos, corrosive chemicals	geometry, sampling, uranium mass determination		
Degreasing contaminated equipment	K-1024, K-1035, K-1401, K-1410, K-1420	Solvents, Freon-113, TRU, Tc-99, fission and uranium daughter products	Film badge or TLD, ventilation, bioassay	Moderately effective when used correctly	1945-1985
Disassembly of stuck shut G-17 cell block valves	K-1420	RAD, UF_6, HF, UO_2F_2, TRU, fission and uranium daughter products, noise, high-temperature surfaces, NC	Film badge or TLD, PPE, bioassay, UF_6 Negative procedure, disassembly procedure, shop evacuation, ventilation, geometry, sampling, uranium mass determination	Effective when used correctly	1954-1984
Distillation of contaminated liquids (except water)	K-101, K-1303, K-1410, K-1413, K-1420	Mercury, fluorcarbons, and chlorine trifluoride	Film badge or TLD, PPE, bioassay	Effective when used correctly	Late 1940s - 1985
Document reproduction	K-1001-B, K-1004-D	Naphtha, acids, ammonia, methyl alcohol, high-temperature surfaces, solvents	PPE	Effective when used correctly	1943-1995 (K-1001-B) 1996 (K-1004-D)
Draining cold traps	K-1131	RAD, UF_6, UO_2O_2, HF, TRU, NC	Film badge or TLD, PPE, bioassay, sampling	Effective when used correctly	1943-1984
Duct maintenance	Process buildings	RAD, UF_6, HF, UO_2F_2, PCBs, fluorine, strychnine in feces	Film badge or TLD, PPE, bioassay	Effective when used correctly	1943-1984
Electrical maintenance	All buildings	RAD, PCBs, solvents, asbestos, noise, high voltage, oxygen deficient confined spaces	PPE, electrical work permits, job hazard analyses	Effective when used correctly	1943-1997

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Experiments with irradiated fuel, Tc-99, and waste materials	K-1004J, K-1405-6, K-1413	RAD, Tc-99, TRU, chlorine trifluoride	Film badge or TLD, PPE, ventilation, special air sampling, bioassay, glovebox, self-reading dosimeters	Moderately effective when used correctly	1948-1952
Extraction of uranium from solid materials	K-131, K-132, K-1303, K-1410, K-1420	Uranium and/or TRU	Film badge or TLD, PPE, ventilation, bioassay	Moderately effective when used correctly	1948-1995
Feed plant operations	K-1131	RAD, fluorides, UF_6, uranium dust, heat, noise	Film badge or TLD, PPE, ventilation, bioassay	Moderately effective when used correctly	1950-1961
Fire box cleaning	K-1501 steam plant and K-701 powerhouse	Airborne arsenic from coal combustion, noise	PPE, air monitoring after discovery of hazard in late 1989; only paper mask worn prior to 1989	Moderately effective when used correctly; ineffective before 1989	1943-1984
Fire and emergency response	All	See full range of hazards described for all Plant facilities	Film badge or TLD, PPE, contamination surveys, bioassay	Moderately effective when used correctly	1943-1997
Flange grinding	Process buildings, K-1231, K-1303, K-1401, K-1410, K-1420	RAD, UF_6, HF, UO_2F_2, TRU, uranium daughter products, Tc-99, noise, heat, asbestos, cadmium, nickel fumes	Film badge or TLD, PPE, bioassay, decontamination, ventilation	Effective when used correctly	1945-1984
Fluorination of irradiated fuel slugs to produce UF_6	K-1004J	RAD, uranium, TRU, and fumes from fluorine, chlorine, and trifluoride	Film badge or TLD, PPE, ventilation, glovebox, bioassay, self reading dosimeters	Effective when used correctly	Early 1950s
Food service preparation and delivery	All buildings	UF_6, RAD, STF, cleaning agents	Ventilation	Ineffective	1950s-1984
Groundskeeping	All	RAD, PCBs, asbestos, arsenic, fungicides,	Film badge or TLD, PPE, bioassay, access control	Moderately effective when used correctly	1943-1997

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Groundskeeping (continued)		hexavalent chromate, insecticides, herbicides, radioactive dust			
Guard patrolling	All buildings	See full range of hazards described for all Plant facilities	Film badge or TLD, PPE, contamination surveys, bioassay	Moderately effective when used correctly	1943-1997
Guard drills and calisthenics	K-33, K-725	See full range of hazards described for all Plant facilities	Film badge or TLD, contamination surveys, bioassay	Moderately effective when used correctly	1950s-1990s
Incinerator operations	T-8, K-1031, K-1421, K-1435	RAD, PCB, solvents, metals	Over time, included: film badge or TLD, PPE, bioassay	Unknown	1991-1997 (K-1435) 1947-1986 (Others)
Industrial photography	All buildings	See full range of hazards described for all Plant facilities	Film badge or TLD, bioassay	Effective when used correctly	1943-1997
Instrument maintenance	Process buildings, satellite shops, K-1024, K-1035, K-1401	RAD, HF, UF_6, TRU, Tc-99, uranium daughters and fission products, radium, acids, solvents, mercury, heavy metals, high temperature surfaces, cyanide, phosgene	Film badge or TLD, PPE, bioassay, decontamination, ventilation	Effective when used correctly	1943-1997
Jetting/Venting	K-25, K-27, K-29, K-31, K-33, K-1401	RAD, UF_6, HF, UO_2F_2, TRU, uranium daughter products, Tc-99, fluorinated hydrocarbon coolant, fluorine, and chlorotrifluoride released to environment	Film badge or TLD, bioassay, procedures specified limiting venting to only purging cells with < 10 ppm UF_6	Effective when used correctly	1945-1987
Laboratory operations	K-1004A, B, C, D, J, and L; K-1006; and miscellaneous laboratories	RAD, UF_6, HF, F, asbestos, acids, solvents, bases, mercury, nickel powders, epoxy, resins, noise, nickel carbonyl	Film badge or TLD, PPE, bioassay, permits, procedures, chemical hygiene plan, lab hoods	Effective when used correctly, although lab hoods were frequently inoperable or ineffective; building ventilation circulated toxic vapors and gases	1946-1985

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Land-farming	K-1070A Landfarm, K-1070C/D, K-1414 cylinder yard, Flannigans Loop Road, Contractor burial ground	Uranium, PCBs	Unknown	Unknown	1982-1985
Landfill operations	K-901A, K-1066A, K-1070A, JA Jones disposal area, Contractor spoils area	Asbestos and ash from coal-fired plant, dust from contaminated building rubble, mercury, solvents, lead paint	Administrative controls on disposal items; in early 1980s added controls on asbestos and building rubble disposal	Effective when used correctly	1940s-1980s
Laundering and collecting contaminated clothing	K-1015, K-1301, and all operations buildings	RAD, beryllium, asbestos, PCBs, TRU	Film badge or TLD	Moderately effective when used correctly	1946-1984
Lithium hydride machining	K-1401	Lithium	PPE	Effective when used correctly	1943-1997
Lithium relocation and repackaging	K-25	LiOH	Dust masks, monthly surveillance, drum overpacking	Moderately effective when used correctly	1974-mid-1980s
Lubrication	All	PCBs, solvents	PPE, decontamination	Effective when used correctly	1943-1997
Machining of various materials	K-725, K-1401	Lead, UF_6, solvents, uranium, dust from beryllium, lithium hydride, stainless steel, lithium hydroxide monohydrate, Li_2O, H_2	PPE, ventilation, glovebox, sensors, alarms	Moderately effective when used correctly	1943-1997
Manufacturing centrifuge equipment	K-1004, K-1200, K-1052	Fiberglass, epoxy resins and adhesives, solvents, acids	PPE, ventilation	Moderately effective when used correctly	1960-1985

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Mercury handling and recovery	K-1004-D, K-1024, K-1035, K-1301, K-1303, K-1401, K-1420	Spills, mercury vapor and contamination	PPE, containment, decontamination, ventilation	Effective when used correctly	1943-1980s
Operation and maintenance of uranium recovery system (by solvent extraction and other uranium solution processing and storage)	K-131, K-132, K-1303, K-1410, K-1420	RAD, TRU, Tc-99, airborne uranium, radioactive effluents, NC	Film badge or TLD, bioassay, PPE, effluents were sampled and release limits were applied, geometry and sampling	Moderately effective when used correctly	1945-1985
Oxidation of recovered uranium compounds	K-131, K-1303, K-1410, K-1420	Soluble and insoluble uranium compounds	PPE, ventilation	Moderately effective when used correctly	1948-1985
Plating	K-1004C and J, K-1410, K-1420	Nickel, cyanide, ammonia, hydrogen cyanide, acids, bases, solvents	PPE, ventilation	Effective when used correctly	1943-1997
Product withdrawal during normal operations	K-25, K-413	RAD, UF_6, HF, UO_2F_2, Tc-99	Film badge or TLD, PPE, stay time, worker rotation, bioassay, ambient air flow	Effective when used correctly	1945-1984
Pulverizing and screening operations and maintenance	K-1231, K-1420	RAD, dust containing uranium, fission products; thorium, TRU (including Np and Pu)	Film badges or TLD, PPE, bioassay, ambient air flow	Moderately effective when used correctly	1951-1984
Recovery of uranium solutions by precipitation, filtration, and solvent extraction	K-131, K-132, K-1303, K-1410, K-1420	RAD, uranium and transuranics	Film badge or TLD, PPE, ventilation, bioassay, ambient air flow	Moderately effective when used correctly	1948-1985
Recycling uranium from vacuum collectors to process	K-1131, K-1410, K-1420	RAD, uranium dust	Film badge or TLD, PPE, bioassay, ambient air flow	Moderately effective when used correctly	1950s

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Reduction of PUREX UO_3 to UO_2 with H_2	K-1405-6	Uranium oxides	Film badge or TLD, bioassay, PPE, ambient air flow	Moderately effective when used correctly	1951
Reduction of UF_6 to UF_4	K-1405-6	Uranium, HF, acids, solvents	Film badge or TLD, bioassay, PPE, ambient air flow	Moderately effective when used correctly	1950s
Release response	All	RAD, radioactive materials	Film badge or TLD, PPE, bioassay, ventilation, decontamination procedures, response kit	Effective when used correctly; ventilation systems were frequently inoperable	1945-1984
Removal of "000" compressors stub shaft	K-1420	RAD, UF_6, HF, UO_2F_2, TRU, fission and uranium daughter products, NC, burns, noise	Film badge or TLD, PPE, bioassay, UF_6 Negative procedure; ventilation, pit evacuation, sampling, uranium mass determination	Effective when used correctly	1954-1997
Removal of compressor seals	Process buildings, test loops, K-1420	RAD, HF, UO_2F_2, TRU, fission and uranium daughter products, high-temperature, noise	Film badge or TLD, PPE, bioassay, UF_6 Negative procedure, ventilation, evacuation	Effective when used correctly	1945-1997
Removal of converter shell internal fixtures	K-1401, K-1420	RAD, UF_6 deposits, UF_6, HF, UO_2F_2, TRU, fission and uranium daughter products, high temperature surfaces, noise	Film badge or TLD, PPE, bioassay, UF_6 Negative procedure, furnace purging, evacuation	Effective when used correctly	1945-1997
Replacement of full UF_6 cylinder valve	Various	RAD, UF_6, HF, UO_2F_2, TRU, fission and uranium daughter products	Film badge or TLD, PPE, bioassay, repair procedure, cooling cylinder to sub-atmospheric, and emergency response procedures	Effective when used correctly	1945-1997
Roof access	All buildings	HF, uranium, other chemical fumes	Bioassay, roof access controls	Moderately effective when used correctly	1943-1997
Sand blasting	K-1410	Silicon dioxide	PPE, ventilation	Effective when used correctly	1943-1997

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Smelting and associated milling and grinding	K-1037C, K-1420	RAD, HF, UF_6, airborne uranium, TRU, nickel carbonyl, aluminum	Film badge or TLD, PPE, air samples, bioassay	Moderately effective when used correctly	1943-1997
Solvent, oil, and chemical recovery	K-101, K-131, K-1030, K-1232, K-1303, K-1405-6	Solvents, volatile organic materials, heavy metals (except mercury)	Film badge or TLD, PPE, air samples, bioassay	Moderately effective when used correctly	1943-1994
Spraying cooling towers with fungicide and corrosion inhibitors	All process support cooling towers	Fungicides, acids, arsenic, chromates, Legionnaire's Disease bacteria, asbestos, noise, STF	Unknown	Unknown	1950s-1980s
Thermal diffusion operations	S-50 Complex, K-724, K-725	Beryllium, mercury, uranium	Unknown	Unknown	1944-1950
Transformer maintenance	All buildings	RAD, solvents, high voltage, PCBs, asbestos, confined space	PPE, electrical work permits, ventilation	Effective when used correctly	1943-1997
Unplugging feed plant transfer lines, hoppers, and conveyers using sledge hammers and rods during normal operation	K-1031, K-1420	RAD, UF_6, TRU, uranium, fission products, noise	Film badge or TLD, PPE, bioassay, ambient air flow	Moderately effective when used correctly	1950-1961
Unplugging fluorination towers	K-1031, K-1405-6, K-1420	RAD; UF_6, HF, and fluorine gases; dust containing uranium and concentrated daughter products, fission products, and TRU; noise	Film badges or TLD, PPE, stay time, bioassay, ambient air flow, geometry, and sampling	Moderately effective when used correctly	1954-1984
Uranium powder conveyer, hopper, and other equipment maintenance and replacements	K-1031, K-1420	RAD, UF_6, TRU, Tc-99, uranium, fission products, noise	Film badge or TLD, PPE, bioassay, ambient air flow	Moderately effective when used correctly	1950-1984

Table B-1. Oak Ridge Gaseous Diffusion Plant Principal Hazardous Activity Evaluation Summary: 1943-1997 (Continued)

Activity Description	Plant Location(s)	Potential Hazard(s)	Hazard Control(s)	Hazard Control Effectiveness and Use	Time Period
Welding	All process and support buildings	RAD, UF_6, HF, UO_2F_2, acids, uranium daughter and fission products, asbestos, heat, high-temperature surfaces, phosgene, nickel fumes	Film badge or TLD, PPE, bioassay	Effective when used correctly	1943-1997

APPENDIX C

PRINCIPAL TREATMENT AND DISPOSAL FACILITIES

Table C-1 summarizes the major treatment and disposal activities conducted at ORGDP from 1943 to 1997 and describes the locations and types of waste materials. Information is provided on the period of operation, the types of materials involved, and the current status. All listed facilities have been the subject of a CERCLA action, have been closed pursuant to RCRA, are awaiting remediation under CERCLA, or are being managed under the inactive sites surveillance and maintenance program.

Under "Status," FS refers to proposed actions as per the "D-zero Feasibility Study."

Table C-1. Treatment and Disposal Facilities: 1943-1997

Facility Name	Operating Period	Material/Waste	Status
J.A Jones Disposal Area	1944-1945	Concrete batch plant residue and disposal of demolition debris	Demolished, no longer under discrete surveillance; institutional controls to maintain soil cover (FS)
K-25 Site Contractor's Spoil Area; also known as the TVA Borrow Pit and the ORGDP Contractor Burial Ground	1974-1985	Past operations involved use as a spoils area for steam plant ash, roofing debris, oil filters, chromate sludge; records also indicate hazardous and radioactive material	Area access controlled by locked gate; still burning pallets; during this inspection found items other than pallets recently burned; no radioactive contamination detected
K-25 Site North Trash Slope	Early 1940s to mid-1950s	Scrap metal, lumber, common trash; also oils and solvents	Cleaned and now used as cylinder storage yards
K-131 Maintenance Shop	1945-1985	Carbon tetrachloride (CCl_4) recovery operation; large amounts of TCE also reclaimed	Slated for remedial action under D&D; either institutional controls or soil excavation (FS)
K-710 Sludge Beds and Imhoff Tanks	1943-1978	Sewage sludge potentially containing radioactive contamination; Imhoff tanks have radiological sediment	In the inactive sites surveillance and maintenance program (Flush sediments from K-710); institutional controls to restrict excavation (FS)
K-720 Fly Ash Pile	1944-1962	Ash from K-701 coal fired plant; sewage sludge applied for pH control	In the inactive sites surveillance and maintenance program
K-722 Area Landfarming and Round House Road	1982-1984	About 1,000 gallons (K-722) and 80,000 gallons (Round House) of used but reportedly non-contaminated oil used for dust control on roads	K-722 not maintained as discrete surveillance; Round House Road now paved; No Action (FS)
K-770 Scrap Metal Yard and Contaminated Debris	1940s and 1960s-1997	Used as oil storage area in 1940s, then for scrap metal storage in 1960s; included radioactive and, asbestos-contaminated materials, and aluminum items	Readily identifiable RCRA items removed in FY 1994; in the inactive sites surveillance and maintenance program
K-895 Cylinder Destruction Facility	1965-1975	UF_6, HF, and combinations of halides and chlorofluorocarbons; soils exceed industrial risk levels; cylinders shot by high-powered rifle; contents drained to K-901-A pond	CERCLA Action complete; excavate soils to two feet, backfill to grade (FS)

Table C-1. Treatment and Disposal Facilities: 1943-1997 (Continued)

Facility Name	Operating Period	Material/Waste	Status
K-900 Bottle Smasher	1980-1988	Used to destroy the contents of various organic materials (methyl ethyl ketone, ethers)	RCRA Clean, closed
K-901-A Holding Pond	1950s-1990s	Disposal of cylinders from the K-895 Destruction Facility; also chemical and sludges from cooling water treatment and blowdown, including chromate, zinc, and polyphosphates; include materials from storm drain, groundwater, and recirculating cooling water system	CERCLA Action complete to drain pond and remove cylinders; monitor surface water, posting for contaminated sediments (FS)
K-901-A North Waste Disposal Area; also known as K-901-A Sanitary Disposal Area	1940s to mid-1970s	Construction material, uranium-contaminated roofing materials, treated wood from cooling towers, and paint cans; soils exceed industrial risk levels; received non-hazardous debris from contractors and maintenance activities; possible uranium, Tc-99 and other radionuclides	Install two-foot soil cover, institutional controls to restrict excavation; maintain postings/ soil cover (FS)
K-901 South Waste Disposal Area; also known as K-901-A Contractor's Waste Disposal Area	Early 1950s to mid-1970s	Roofing material, concrete rubble from enrichment buildings, wood from cooling towers, and asbestos; possible uranium contamination	Part of Holding Pond CERCLA Action; install two foot soil cover; institutional controls to restrict excavation, posted (FS)
K-1007-P1 Holding Pond; also known as K-1007-B Pond	1950s-1997	Estimated 2,200 gallons of laboratory waste discharged annually until 1985 (77,000 gallons); presently used to retain storm water; releases continue from laboratory stormdrains SD-100 and SD-110	PCB contamination detected; active unit NPDES permitted since 1974
K-1030 Maintenance Shop	1940s-1980s (electrical maintenance shop)	There was a carbon tetrachloride recovery system in the early 1950s	No Action (FS)
K-1045 Valve Shop	Unknown-1985	Originally used as a boiler house, then as an incinerator; last used as a valve certification laboratory	No Action (FS)
K-1064 Drum Storage and Burn Area	1950s and 1960-1979	Used in the 1950s for burning waste paints, organic waste and radiological contaminated waste	Excavate two feet of soil (in specified areas); remove scrap metal, backfill, and grade;

Table C-1. Treatment and Disposal Facilities: 1943-1997 (Continued)

Facility Name	Operating Period	Material/Waste	Status
K-1064 Drum Storage and Burn Area (Continued)		oils; in 1960, used to store 1,838 drums of solvents, waste wood and radioactive contaminated waste oil until removal in 1979	institutional controls to monitor groundwater (FS)
K-1070-A Landfarm	1979-1985	Mixture of 190,000 gallons of K-33 cascade lubricating oil and 5,000 cubic feet of fuller's earth	Site covered /vegetated; "No Further Investigation" request submitted in 1997; slated for No Action (FS)
K-1070-A Old Contaminated Burial Ground	Late 1940s to March 1976	Low-level contaminated waste and mixed chemical waste; potential pyrophoric material; 62 graves and 26 trenches constructed; obvious radiological plume (almost entirely beta)	K-1070A Burial Ground Record of Decision (ROD) for groundwater
K-1070-B Old Classified Burial Ground	Early 1950s-1976	Lead, uranium, aluminum, copper, beryllium, asbestos, and contamination from liquid organics and hydrocarbon oils	Removal Action under CERCLA complete
K-1070-C/D Classified Burial Ground	1974-1989	Strong oxidizing agents, classified material-contaminated materials, strong reducing agents, organic solvents, and pesticides; expected amounts 9,100 gallons of solvent and 1,600 pound of chemicals; also oil (2,000 gallons) contaminated with relatively high levels of uranium were landfarmed	Removal Action under CERCLA complete; separate ROD for groundwater DNAPLs and G-pit related hot spots
K-1070-F Construction Spoil Area; also known as K-1070-F Old Contractors Burial Ground (Duct Island)	Early 1970s-1978	Construction debris, roofing scrap, asbestos, and fuller's earth; no indication of hazardous or contaminated material, but early 1970 records not available	Install two-foot soil cover; vegetate; institutional controls to restrict excavation, monitor groundwater (FS)
K-1085 Old Firehouse Burn Area (Powerhouse)	1944-1960	Estimated 95,000 gallons of waste oils and solvents including TCE, carbon tetrachloride, and PCB-contaminated paints; waste oil incinerated in a pit until 1951; open burning of some PCBs and solvents until 1960s	No Proposed Action (FS)
K-1099 Blair Quarry; also known as Blair Road Quarry and Blair Hollow Quarry	1945-1957	Open burning of trash and debris; also indications that waste oils and possibly PCB were burned; burial of	Without groundwater action; install two-foot soil cover; institutional controls to restrict excavation

Table C-1. Treatment and Disposal Facilities: 1943-1997 (Continued)

Facility Name	Operating Period	Material/Waste	Status
K-1099 Blair Quarry; also known as Blair Road Quarry and Blair Hollow Quarry (Continued)		construction debris and PCB/ radionuclide debris; groundwater sampling showed alpha activity above drinking water standards	
K-1232 Chemical Recovery Facility and Lagoon; also known as K-1232 Treatment Facility Lagoon and K-1232 Chemical Recovery Facility	1970s-1994 (1984-1987, processed corrosive wastewater from Y-12)	Volatile organics, polynuclear aromatic hydrocarbons, and heavy metals; Remedial Investigation reports indicate several radioactive contaminated areas	Fill basins; institutional controls to restrict excavation
K-1303 Air Model Test facility (also known as Fluorine Facility and Decontamination Building)	1948-1956	Mercury Distillation Unit; operations included recovery and stabilization of uranium contaminated oil; chlorine trifluoride removed from T-53 in 1953 is also stored there	Excavate slab, plenum, loops, and surrounding soil; backfill, grade, vegetate; additional action taken under K-1303 Mercury soil unit (FS)
K-1405-6 High-Temperature Lab	1946-1991	Used for eight separate activities including pilot plant for Hanford reactor tails and as a disposal plant for fluoride	This unit is slated for D&D in fiscal year 2000; No Action (FS)
K-1407-B Holding Pond	1943-1988	Organic and metal hydroxide precipitates, uranium compounds, traces of transuranics, degreasers, oils, and PCBs; these came mostly from the K-1407-A Neutralization Pit	Remedial action complete; post-remedial action groundwater monitoring; also closed under RCRA
K-1407-C Retention Basin	1973-1988	Organic and metal hydroxide precipitates, uranium compounds, traces of transuranics, degreasers, oils, and PCBs; sludge from K-1407-B Holding Pond	Remedial action complete; post-remedial action groundwater monitoring; also closed under RCRA
K-1410 Neutralization Pit (Nickel Plating Facility)	1963-1979	Acids and bases used in nickel-plating process, radioactive contamination; surface soils exceed industrial risk levels	Nickel-plating facilities demolished in 1999; propose to remove slab and underlying soils; excavate soils to two feet, backfill, institutional controls
K-1419 Sludge Fixation Plant	1987-1988	Sludges from K-1407 B & C, and K-1232, 4.1 million gallons of material processed from K-1407B and C closure; wastes classified as mixed (traces of radiological contamination); TCSA incinerator ash, and	Demolished as part of RCRA closure; certified clean and closed in 1997; proposed to remove slab, remaining soils, backfill, grade (FS)

Table C-1. Treatment and Disposal Facilities: 1943-1997 (Continued)

Facility Name	Operating Period	Material/Waste	Status
K-1419 Sludge Fixation Plant (Continued)		thickener sludge from K-25 along with wastes from other OR sites	
K-1421 Incinerator Poplar Creek Disposal Area	1954-1986	PPE, waste oil sludge, uranium sludge from Miller's Fluorinated Lubricating oil recycling project; airborne emissions spread contamination to K-1420 soils, which exceed industrial risk standards	Covered by K-1420 contaminated soil action; excavate soils to two feet, backfill, institutional controls
Poplar Creek Disposal Area	Early 1940s-1975	Non-combustible building materials, concrete, asphalt, and steel; combustible, but reportedly non-hazardous, materials burned at site	Site of TVA electrical substation; No Action planned (FS)